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A PORTABLE CHARCOAL KILN

Using the Chimney Principle

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FOREWORD

FOR a number of years the Connecticut State Forestry Department has manufactured charcoal in brick kilns of conventional design. These are about fifty cord capacity and are operated on the same principle as the old type beehive kilns or pits which had a sod cover. The purpose of this was to determine whether charcoal could be made from local woods in competition with by-product charcoal from wood distillation plants. While a satisfactory grade of charcoal can be made in stationary kilns of this type, it was found that under Connecticut conditions certain charges against the operation were disproportionately high. Chief of these were the cost of trucking the wood to a central location, the amount of attention required during coaling and the relatively high charging and discharging costs.

When the Connecticut Norris-Doxey Farm Forestry Research Project on Fuel Wood was set up in the fall of 1939, it was decided to include an experiment with portable kilns in an effort to overcome some of the difficulties cited above for the stationary brick kilns. This was to be the particular contribution of the Agricultural Station which financed the materials and contributed the time of Mr. A. R. Olson, Technician in Forestry, for some eight months. The cooperating organizations are the Connecticut Agricultural Experiment Station, The Connecticut State Forestry Department, The Northeastern Forest Experiment Station, The Department of Mechanical Engineering, Yale University, and the Connecticut Forest and Park Association.

A review of the literature indicated that many types of more or less portable, metal kilns had been described in this country and abroad. Most of these are, for practical purposes, miniatures of the larger beehive kiln and are operated on the same principle. Except for the element of portability they seemed to offer few advantages over the latter. However, one type of kiln devised by Swedish engineers and described in *Skogen*, a Swedish forestry periodical, appeared to offer distinct possibilities. This was the so-called "chimney" kiln. The information available in *Skogen* was very meager and a letter to the editors brought no response, due to disturbed European conditions. It was decided, however, to attempt the construction of a kiln using the chimney principle and a sub-project for this purpose was set up under the main Connecticut Fuel Wood Study. Mr. Olson began the work during the spring of 1940 and during the past year has built three chimney kilns, a description of the design and operation of which forms the body of this bulletin.

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TABLE OF CONTENTS

PLATE A. Front view of the four cord kiln with gas outlet stack removed.

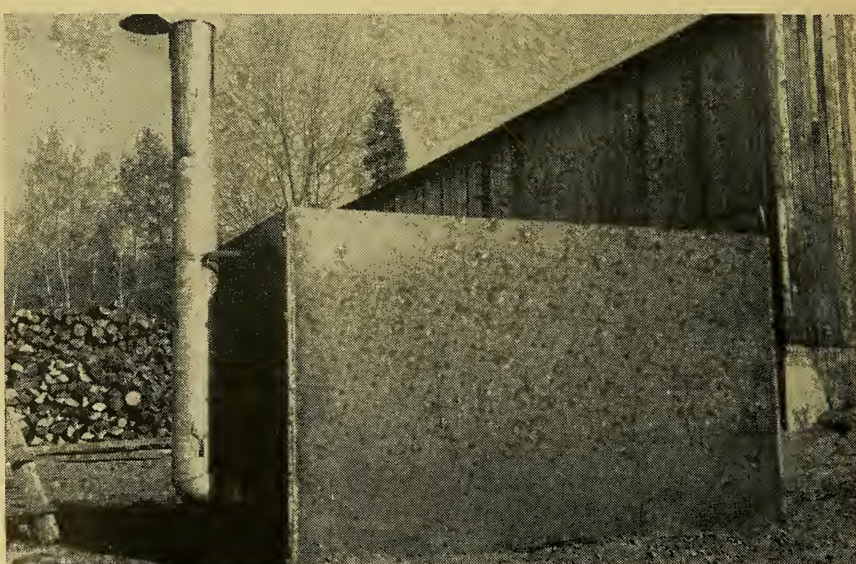

PLATE B. Side view of the one cord kiln.

Courtesy of the United States Forest Service

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THE PRINCIPLES OF COALING

IF wood is heated in the presence of a limited supply of air, a distillation process takes place whereby water vapor and other volatile products are driven off as gas or smoke, and charcoal remains as the end product. There are many types of apparatus for the conversion of cord wood to charcoal, but these may be grouped into three general classes:

a. In which wood is charred in closed containers by the application of outside heat and without the admission of air.

b. In which wood is charred in the presence of a steady but limited influx of air, the initial heat being supplied by igniting a portion of the charge.

c. In which features of both (a) and (b) are combined.

The apparatus described below comes under Class (b). In it, only a relatively small part of the wood in the kiln is in the process of coaling at any given time. The portion which is in the state of change from wood to coal is called the coaling zone. This is but a few inches in thickness and moves progressively from one part of the kiln to another. Behind the zone is charcoal and ahead of it, uncoaled wood. The form of this coaling zone and the direction of its movement depend on the shape of the kiln. In kilns of circular cross-section, the coaling zone is shaped like a shallow, inverted cone and moves from top to bottom of the kiln. In kilns of rectangular cross-section, as in those described below, the zone is shaped like a thin rectangular prism, two edges of which are perpendicular to and touching the sides of the kiln, and whose movement is horizontal from one end of the kiln to the other. The zone is inclined in the direction of movement, the angle from the vertical varying from about 30° to 75°, depending on the distance from the starting point. See Figure 1.

The successful coaling of a charge of wood consists in conducting this zone through the kiln in the right direction and at the right speed. Many factors are involved but assuming a kiln of correct design, with the wood properly stacked and ignited, the most important factor is the regulation of the air supply to the coaling zone.

THE "CHIMNEY" KILN

The basic difference between the "chimney" kiln as described in this paper and kilns of the conventional beehive type lies in the method of regulating the flow of air *into* the kilns and emission of smoke (water vapor and gases) *from* the kiln. In the latter, there are several air inlets and smoke outlets in different parts of the kiln, the number varying with its size. These require a good deal of attention during the coaling period to insure an even "burn". In the former (chimney kilns) all the smoke can be led away through one pipe. The air inlets are all localized in one part of the kiln. It was found during a considerable number of burns that, except for the initial firing period, practically no attention was required during the coaling of the charge.

CONSTRUCTION OF THE KILNS

The objectives sought in the design of the kilns were:

1. Ease of construction and assembly
2. Ease of charging with wood and of discharging charcoal
3. Minimum of attention during operation
4. Relatively high portability

During the past year three chimney kilns have been designed, built and operated, one cylindrical, with a capacity of four cords, and two rectangular, of one and four-cord capacity, respectively. The cylindrical type was provided with one air inlet and one gas outlet and theoretically is the best design. However, it was rather difficult and expensive to build and to charge, and was given up in favor of the rectangular type, to a description of which the rest of this paper is confined.

These kilns are an assembly of rectangular panels made up of 10-gauge sheet metal, reinforced with angle and T iron. Detailed working drawings for the construction of the panels are included together with sketches showing their assembly to form the kilns.

A major portion of the work on the panels can be performed with ordinary tools. A heavy-duty electric drill speeds up the work but is not absolutely essential. If the work is done at home, the material should be ordered cut to size before delivery. Stock sizes have been used wherever possible. In some cases odd sizes are specified but these have been planned with a minimum of waste. A small amount of welding is needed to reinforce the riveting between the sheet metal and the angle and T iron, and to provide a tight seal at some of the panel junctions. The collar, into which the gas-outlet stack is inserted, should be made by a blacksmith. Prior to bolting the collar in place, the inner face of the flange should be smeared with asbestos cement (flake asbestos and water) before tightening the bolts to prevent gas leaks. To avoid warping of the panels during drilling and riveting, this work should be done on a solid flat surface. When finally assembled, the panels are fastened together or to the frame by bolts or pins which pass through holes in the reinforcing angle and T irons. It is recommended that these holes be drilled with the panels held in correct position relative to each other or to the frame to insure proper alignment when pins and bolts are inserted.

The one-cord kiln is assembled by bolting and pinning the five panels together directly. The increased number of panels in the 4-cord kiln necessitates the use of a light frame made of T and angle iron in conjunction with the panels. To prevent undue warping of the metal during the initial firing period when temperatures are highest, the rear end or firing panel, and the adjacent side panel are insulated on the inside. This is done by spacing a sheet of 18 gauge steel 1½ inches away from the 10 gauge steel, which forms the panel proper, and filling the space between the two with asbestos cement (flake asbestos and water) or mineral wool.

It is recommended that a piece of one-inch wire mesh (made of 10-gauge wire), with dimensions of 4 by 4 feet for the one-cord kiln and 5 by 8 feet for the four-cord kiln, be wired to the angle iron uprights on the inside of the front panel. This mesh is not shown in the working drawings. Its purpose is to prevent falling charcoal from blocking the gas outlet.

ERECTION OF KILNS

Prior to actual setting up, the ground on which the kiln is to be placed must be carefully leveled off and the soil firmed. Next, some good sized, flat-topped stones are bedded in and leveled up to form the supports for the corners of the kiln. Other stones should also be bedded in at 4-foot intervals along each side and end to prevent sagging of the panels.

The One Cord Kiln

To assemble, place one side and one end panel in position on the foundation and bolt together. Then place the other side and the other end panel in place and bolt to the two already assembled. Then square up the corners and drop the top panel on to the shelf formed by angle iron near the inside top edge of the side and end panels. Next bolt the top panel to the end panels and pin it to the side panels. The inner or floating edge of the baffle plate is supported in a horizontal position by bricks so placed as to offer the minimum obstruction to air coming in at the air inlets. (Bricks are used instead of permanent legs because they can be easily removed when cleaning the kiln). The wire mesh mentioned above is fastened in place. This completes the assembly except for sealing which will be described below.

Four-Cord Kiln

To assemble, bolt the frame members in place on the foundation. Then raise the end panels into place and bolt to the frame. Next lay the three top panels in place and bolt to the frame. The side panels are then raised into place and bolted and pinned. The inner or floating edge of the baffle plate is supported in position by bricks as in the one-cord kiln. The wire mesh is fastened to the angle iron uprights as in the one-cord kiln. A 4-inch I-beam 12 feet and 4 inches long is now placed lengthwise of the kiln directly over the center frame member and fastened to the latter by bolts for strengthening the frame. This completes the assembly of the kiln.

Sealing

All horizontal junctions between panels and between a panel and

the ground can best be sealed with fine mineral soil. The channel formed by the junction of the top panel with the side and end panels is so sealed. A layer of soil one to two inches thick may be kept spread over the top of the kiln for this purpose. Sealing between the panels and the ground is accomplished by banking with soil.

Sealing of vertical joints in the one-cord kiln is done by loosening the bolts between the side and end panels, prying the panels apart and crowding asbestos cement (flake asbestos and water) into the joint. Tightening the bolts completes the seal. (This may be done for one side when the kiln is set up. The other side, which must be removed each time for loading, will be sealed after loading).

Vertical joints in the four-cord kiln are sealed by plastering the angle between the web and flange of the T iron, into which the side panels fit, with asbestos cement before pinning and bolting the panels in place. Sealing may be done on four of the six side panels when the kiln is set up. The other two (usually those adjacent to the ends on the same side of the kiln) are not sealed until after the kiln is loaded.

A can of lime mixed to the consistency of a very heavy cream is useful in patching any small leaks (indicated by escaping smoke) which may develop during coaling. It is readily applied with a stiff paint brush.

LOADING

One-Cord Kiln

Two lines of stringers made of cordwood, 4 inches in diameter, are laid on the ground lengthwise of the kiln and spaced about 18 inches from either side. Next a piece of wadded burlap soaked with kerosene is placed near two firing ports[1] (Figure 3) and some thoroughly dry kindling, also soaked with kerosene, is piled on top of the burlap. Then the wood is closely stacked in the kiln in a manner similar to that used in making up a pile of cordwood. The smaller, drier pieces of wood should be placed directly above the kindling. Any large pieces should be distributed through the charge, preferably in the upper half of the kiln. If any brands (partially charred sticks) are available, a few distributed through the dry wood above the kindling will be helpful in getting the fire started. A typical loading is illustrated in Figure 2.

Four-Cord Kiln

In this kiln the wood is stacked horizontally in two parallel ranks with the long axis of the sticks perpendicular to the sides of the kiln. Each rank may be considered as a separate unit which is stacked exactly as described for the one-cord kiln. For the whole charge there will be four firing ports and four units of kindling and burlap, instead of two of each as in the one-cord kiln. As the wood is piled in, a baffle made of 20-gauge sheet metal, 2 feet wide and 6 feet long, is placed vertically between the two ranks of wood at the rear end of the kiln with one long side touching the rear end panel (Figure 3).

[1]The firing ports are not a part of the kiln proper but are simply holes approximately 2.5 inches by 8 inches wide dug under the edge of the rear end or firing panel to provide a draft during the ignition period. Framing the ports with brick tamped into the soil helps to keep them of uniform size. If this is done a brick may be used as a damper which can be removed and replaced as needed.

It may be tacked to the ends of the sticks to hold it in position during loading or, if desired, it may be reinforced with angle iron and bolted to the end panel. Its purpose is to promote an even spread of fire over the rear end panel.

OPERATION OF THE KILNS

General

Cord-wood is so variable in moisture content, size of stick, species, etc. that no fixed rules for operation, which will apply to all cases, can be laid down. The best that can be done is to describe an operation under reasonably fixed conditions and indicate variations in procedure which will have to be made as these conditions change.

In the following tables are time schedules of operation which have been successfully used for each kiln when charged with well seasoned hardwoods (largely oak), averaging 4 to 5 inches in diameter. An increase in size of wood or in moisture content will require more time for Steps 1, 2, 3, and 4 (see below), and some increase in the air inlet openings in Step 4. Smaller wood or very dry wood requires shorter time and less air.

The amount of air which may be admitted through the air inlets in Step 4 falls within a relatively narrow range. If too much air enters the kiln, coaling proceeds too quickly and the charcoal is overburned, light in weight and breaks up into small pieces. If too little air is admitted, the coaling zone ceases to move forward; the incoming air is apparently all drawn to one place instead of being distributed evenly to the whole coaling zone and local burning of the charcoal results. Manifestations of a burning condition within the kiln are a decided thinning out of the smoke and a change in its color from yellowish or grayish white to blue. It also becomes much more acrid. The heat developed in this local burning is very intense and if it occurs near the kiln walls, these become red hot and may be badly warped. When this condition occurs it is difficult, if not impossible, to start the coaling zone in forward motion again and it is usually best to close and seal the kiln, let it cool and start over again.

By using care and judgement the operator, after a little experience, should be able to time the operations and regulate the air supply so as to produce satisfactory results under varying conditions.

The Purpose of the Several Steps

The charge is ignited by applying a burning taper to the kerosene-soaked burlap placed near the firing ports at the time of loading. All regulation is done by controlling air influx and smoke emission through the several openings built into the kiln shell or temporarily dug beneath the shell. For the location of these openings see Figure 3.

Step 1. Preheating

The firing ports (C) and firing chimneys (D) (made by placing one length of pipe over the openings in the top panel) are open. The gas outlet (B) and the air inlets (A) are closed. With the openings arranged thus the wood near the rear end panel burns freely as in a stove. This step is continued until the rear end panel is uniformly hot over its entire surface. Usually from three-quarters to one hour for the one-cord kiln and from one hour to one and one-half hours for the

Schedule of Operations

One-Cord Kiln

See Figure 3

Step No.	Operation	Approximate Duration Hours	Position of Controls: Firing Ports C	Firing Chimneys D	Gas Outlet B	Air Inlets A
1.	Pre-heating	3/4 - 1	Open	Open	Closed with metal cover	Closed
2.	Developing the Coaling Zone	1 - 1¼	Closed and sealed	Open	Open without stack	Closed
3.	Coaling (a)	1	Closed and sealed	Closed and sealed	Open with stack attached	Open 3¼ inches
4.	Coaling (b)	21	Closed and sealed	Closed and sealed	Open with stack attached	Open 1½ inches
5.	Cooling	24	Closed and sealed	Closed and sealed	Closed with metal cover and sealed	Closed and sealed

SCHEDULE OF OPERATIONS

Four-Cord Kiln

See Figure 3

Step No.	Operation	Approximate Duration Hours	POSITION OF CONTROLS			
			Firing Ports C	Firing Chimneys D	Gas Outlet B	Air Inlets A
1.	Pre-heating	1 - 1½	Open	Open	Closed with metal cover	Closed
2.	Developing the coaling zone	1½ - 2½	Closel and sealed	Open	Open without stack	Closed
3.	Coaling (a)	1	Closed and sealed	Closed and sealed	Open with stack attached	Open 5 inches
4.	Coaling (b)	30	Closed and sealed	Closed and sealed	Open with stack attached	Open 2½ inches
5.	Cooling	48	Closed and sealed	Closed and sealed	Closed with metal cover and sealed	Closed and sealed

four-cord kiln will be sufficient time to accomplish this. Test for uniformity of heating is made by splashing the panel with water which should hiss and not simply evaporate. If the wood is very dry, it may be necessary to partially close the firing ports in order to prevent too much loss of wood by complete combustion.

Preheating is very important. Its object is to bring a considerable volume of wood (that adjacent to the rear end panel) up to coaling temperature rather slowly and evenly. When a sufficient volume of wood has been brought to this temperature, a coaling zone can be drawn forward without difficulty as described below. If the volume is too small or poorly distributed, later manipulation is very difficult if not impossible. *Therefore, be sure that the rear end panel is uniformly hot over its entire surface before proceeding to the next step.* At the end of this step the firing ports are closed and banked with soil.

Step 2. Developing the Coaling Zone

The purpose of Step 2 is to develop a coaling zone from the heated mass of wood described in Step 1 and to start this zone moving through the remainder of the charge toward the front end panel. In Figure 1 several positions of the coaling zone are shown. It will be noted that they are inclined forward in varying degrees. To start the zone moving forward and give it the desired forward pitch, the gas outlet (B) is opened and used temporarily (with stack removed) as an air inlet. The firing chimneys are open as in Step 1. After one to one and one-half hours for the one-cord kiln, or one and one-half to two and one-half hours for the four-cord kiln, the top and side panels should become hot for some distance from the rear end panel, indicating that the coaling zone is developing properly. When the top is uniformly hot for about half the distance toward the front end panel and the sides are uniformly hot for one to 1.5 feet from the rear end panel, Step 2 is completed. At this time the firing chimneys are removed and the holes over which they stand are closed with metal covers and sealed with soil.

Step 3. Coaling (a)

This is a test period of one hour to determine whether Steps 1 and 2 have been performed properly. The gas outlet stack is placed in its collar with sufficient lengths of pipe to extend approximately 42 inches above the top of the kiln. The air inlet slides are opened to 3.25 inches on the one-cord kiln and 5 inches on the four-cord kiln. A good volume of slightly yellowish or grayish white smoke should immediately begin issuing from the stack. This volume should increase slowly. A small or diminishing volume of smoke indicates that Step 2 has not been carried on long enough to bring a sufficient quantity of wood up to the coaling temperature. If such is the case, the controls should again be set as for Step 2 and this step continued for one-half to one hour more before again changing the controls back to the position in Step 3.

Step 4. Coaling (b)

If the volume of smoke continues satisfactory through Step 3, the air inlet slides may be closed to 1.5 inches for the one-cord kiln

or to 2.5 inches for the four-cord kiln. Under ordinary conditions no further attention will be needed until one to two hours before the run is finished. This will be about 21 hours later for the one-cord kiln and about 30 hours later for the four-cord kiln. During the latter part of the "burn", much tar in gaseous form is driven off. This condenses in the stack and may block the gas outlet. To prevent this stoppage the stack should be removed about two hours before the kiln is ready to close, cleaned of tar and replaced. The proper time to do this will be learned by experience but until this is gained, the stack should be removed for inspection several times during the last half of Step 4.

The burning of tar near the air inlets is an indication that coaling is about completed. Prolonging the operation beyond this point may result in a loss of charcoal by combustion.

Step 5. Cooling

The kiln should now be closed for cooling. This is done be removing the stack and replacing it with a metal chimney-hole cover, closing and banking the air inlets and plastering up any small leaks that may have developed. The cooling period is 24 hours for the one-cord kiln and 48 hours for the four-cord kiln.

After cooling, the charcoal should be bagged. Because of the possibility of spontaneous combustion, it should not be placed in a building for at least 48 hours.

Before reloading with wood, the kiln should be raked clean, with particular care to remove any charcoal that may have accumulated under the baffle in front of the air inlets.

BATTERY OPERATION

One-Cord Kiln

This kiln will require about four man-hours to bag a charge of coal and reload with wood. The elapsed time of the coaling period is 24 hours. During this time one to two man-hours of attention are needed, principally during the three hours following ignition, to manipulate the controls and to seal the kiln at the close of the period. An additional 24-hour period is required for cooling during which no attention is needed. Hence the total elapsed time is 52 hours.

One man can tend a kiln through the three to four-hour period after ignition and at the same time unload and reload another kiln. Because these operations cannot be performed concurrently with a one-kiln unit, the latter is inefficient in the use of labor.

A two-kiln unit is efficient in terms of man-hours per cord of wood coaled. By igniting a kiln at 8 A. M. every other day, four cords of wood can be coaled in an elapsed time of eight and one-sixth days with 16 man-hours of labor. Under these conditions a man would be working on the kilns about 25 percent of the time.

A four-kiln unit is somewhat less efficient in terms of man-hours per cord of wood coaled, but would enable the employment of a man full time on the kilns.

Using four kilns, No. 1 is ignited at 8 A. M. and No. 2 at 12 M. of the same day, No. 3 is ignited at 8 A. M. and No. 4 at 12 M. of

the following day. Approximately 52 hours after ignition, each kiln will have coaled through and have been discharged and reloaded. If reloading is completed by 12 M, the new charge is immediately ignited. If reloading is not completed until late afternoon, ignition should be delayed until 8 A. M. the following day.

The schedules suggested may be easily diagrammed. They are based on the assumption that the elapsed time necessary to complete all operations for a kiln is 52 hours, that the operations of tending during the first four hours after ignition and of unloading and reloading can be carried on concurrently and will require about four hours and that labor will be needed only between the hours of 7 A. M. and 5 P. M. In actual practice the operator will devise a schedule, based on the factors which govern his working conditions, which may be quite different from that suggested above.

Four-Cord Kiln

From seven to eight man-hours are required to bag the charcoal from this kiln and reload it with wood. The elapsed time of the coaling period is 36 hours, during which about four to five man-hours are needed to manipulate the controls and later to seal the kiln. An additional 48 hours is required for cooling. The total elapsed time from ignitioin to the end of the cooling period is 84 hours.

A good working unit under these conditions is four kilns. As stated for the one-cord kiln, the best use of man-power is secured when the operations of tending one kiln after ignition and the unloading and reloading of another are done concurrently.

A suggested time schedule for a four-kiln unit is as follows: Ignite one kiln at 8 A. M. on each of four successive days. Eighty-four hours after each kiln is ignited it is ready to unload. Since this is at 8 P. M., unloading and recharging, which require seven to eight hours, are delayed until the following morning. The kilns could be ignited at about 4 P. M. of the same day, but since this would make unduly long hours for the operator, ignition is delayed until 8 A. M. the following day. Thus the second cycle for each kiln begins just five days after the first.

Under this schedule the operator would work eight to nine hours a day for four days, the fifth day he would work four hours, the next four days eight to nine hours each, the tenth day four hours, etc. In addition he would have to spend one-half hour each evening in closing a kiln.

KINDS OF CHARCOAL

Charcoal may vary all the way from a brown coal with a high content of volatile matter to a very light coal of high carbon content from which most of the volatile matter has been driven off. Brown coal burns with much smoke and a yellow flame and is unsatisfactory for most purposes. High carbon coal is usually low in weight in proportion to its volume and tends to break up into small pieces. It burns readily with a blue flame and no smoke. In general the operator will try to produce a coal to suit his market. For the most part, this will be a medium type between the extremes mentioned. Such a coal will be moderately dense, have a carbon content of about

80 percent and break up, on removal from the kiln, into fairly large pieces. It will exhibit a lustrous black surface when broken across the grain and will burn rather slowly with a blue flame and no smoke.

YIELDS

Some 50 burns were made in the one-cord and 12 in the four-cord kiln. A considerable number of these were strictly trial runs to check changes in design and to develop technique of operation described above. Many were made with wood which was only partially seasoned or which contained a considerable amount of decayed sapwood. The yields from those runs which were considered satisfactory ranged from 30 to 40 bushels per cord, based on a 20 pound bushel. It is believed that with sound, well-seasoned, dense hardwoods (oak, maple, birch, etc.) and careful manipulation of the kilns, yields averaging 40 bushels per cord may be expected. This is somewhat lower than the yield recorded for kilns of larger capacity. This is to be expected because, other things being equal, the larger the kiln, the higher the yield of charcoal per cord. It should be pointed out, however, that in the small kilns, savings in hauling wood, filling and emptying the kiln, and in the labor cost of coaling itself, may more than offset higher yields in larger apparatus.

DISCUSSION

The kilns described above represent an effort to adapt the chimney principle as developed by Swedish engineers to the manufacture of charcoal in a portable apparatus. The results are a compromise between a design which theoretically should produce the best results and one which would be suitable to conditions in this country, in particular one which requires a minimum of expense to build and to operate.

The principal advantage in the use of the chimney in conjunction with localized air inlets lies in the fact that, once the coaling of the charge is well under way, little further attention is needed until the kiln is ready to close at the end of the burn. The use of a chimney on a four-cord, cylindrical, metal kiln was not considered satisfactory because of the considerable expense in constructing the internal duct system needed to admit air and emit smoke. Moreover, portable, cylindrical or dome-shaped kilns are relatively expensive to build and to charge with wood. It would seem, however, that a chimney and duct system might be used in large stationary kilns (brick kilns of 50-cord or more capacity) and effect a material saving in labor during the coaling period. As now built, such kilns require almost constant attention during the coaling period of one to three weeks. If the suggested system were applied to such kilns, the ducts should be of tile.

A chimney is used on the rectangular kilns but there is no internal duct system other than that made when stacking the wood. Construction is consequently much simplified. One disadvantage of the rectangular shape is the care needed in order to get a good spread of fire over the rear end panel. The wider this panel, the more attention required. It is believed that a four-cord kiln 6.5 feet high,

5.5 feet wide (to accommodate 5-foot wood) and 16 feet long, would be much easier to handle than the four-cord kiln described above. Its end dimensions would be only slightly greater than those of the one-cord kiln, which is relatively easy to manipulate because of its narrow width. Just how much a kiln could be increased in length without radically changing the design is problematical but no difficulty should be encountered in increasing it to 16 feet, or 4 feet over the larger experimental kiln here described.

ACKNOWLEDGEMENTS

The writers desire to express their gratitude to the many persons and organizations who have given advice or assistance during the construction and operation of the kilns described herein. Special thanks are due to Mr. W. C. Shepard of the Connecticut State Forestry Department for providing a working site, wood and C.C.C. and other labor details; to Mr. Allen Bratton and his associates on the staff of the Northeastern Forest Experiment Station for general advice and for preparation of the working drawings; to Professor Lauren E. Seeley of the Department of Mechanical Engineering, Yale University for help with insulation and other problems; and to Dr. George Pucher of this Station for assistance in the translation of certain foreign language texts.

Bill of Materials

One Cord Kiln

Kind of Material	Dimensions	Front End Panel Fig. 4	Rear End Panel Fig. 5	Top Panel Fig. 6	Side[6] Panel Fig. 7	Total for Kiln
		Number of pieces				
Number 10 ga. Sheet Steel	4'6" x 5'0"	1[1]	1[1]			2
" " " " "	0'10" x 4'2"	1[1]				1
" " " " "	4'6" x 8'0"			1		1
" " " " "	5'0" x 8'0"				1	2
" " " " "	0'3" x 0'6"	4[2]				4
" " " " "	0'8" x 0'8"			2[3]		2
" 18 " " "	4'0" x 4'3"		1			1
" " " " "	4'0" x 2'6"				1	2
Steel Plate 1" x ¼"	4'2"	2				2
" " 1" x ¼"	3'2"	1				1
" " 2" x ⅛"	2'4"	1[4]				1
" " ⅛" thick	0'11½" x 0'11½"	1[4]				1
Angle Iron 1½ x 1½ x ¼	8'0"				1	2
" " 1½ x 1½ x ¼	4'2"	3	1			4
" " 1½ x 2 x ¼	5'0"	2	2			4
" " 1 x 1 x ¼	4'10¼"				2	4
" " 1 x 1 x ¼	4'0"	2				2
" " 1 x 1 x ¼	4'2"	1				1
" " 1 x 1 x ¼	4'4"	1	1	2		4
" " 1 x 1 x ¼	3'0"	1				1
" " 1 x 1 x ¼	4'8½"		2			2
" " 1 x 1 x ¼	8'0"			2	1	4
T Iron 1½ x 1½ x ¼	4'10½"		1		2	5
" " 1½ x 1½ x ¼	4'4"			2		2
Rivets	¼" x 1"	37	57	84	89	356
Machine Bolts	$\frac{5}{16}$" x 7"	1				1
" "	$\frac{5}{16}$" x 1½"	18		6		24
" "	$\frac{5}{16}$" x ¾"	12				12
" "	$\frac{5}{16}$" x 4"	9				9
" "	$\frac{5}{16}$" x 2½"		24			24
" "	$\frac{5}{16}$" x 4½"		6			6
" "	$\frac{5}{16}$" x 2"				12	24
" "	⅜" x 1½"				10	20
Steel Pipe 1" diam.	3"	9	6			15
" " " "	1½"		24		12	48
Steel Pins	$\frac{5}{16}$" x 3"			8		8
Chimney Hole Cover	8"	1[5]				1
Galv. Smoke Pipe, 24 ga.	8"	3-4				3-4
" " " T, 24 ga.	8"	1				1
Wire Cloth, 1" mesh, 10 ga. wire	4'0" x 4'0"	1[5]				1

[1]All from one sheet 5' x 10'.
[2]For air inlet slides.
[3]For firing chimney covers.
[4]For making gas outlet collar.
[5]Not shown.
[6]Number of side panels, 2.

Bill of Materials

Four Cord Kiln

Kind of Material	Dimensions	Frame Fig. 8	Front End Panel Fig. 9	Rear End Panel Fig. 10	Top[1] Panel Fig. 11	Side[2] Panel Fig. 12	Total for Kiln
		Number of pieces					
Number 10 ga. Sheet Steel	6′0″ x 9′0″		1[7]	1[7]			2
“ “ “ “ “	4′0″ x 6′0″					1	6
“ “ “ “ “	4′0″ x 9′0″				1		3
“ “ “ “ “	0′10″ x 8′6″		1[7]				1
“ “ “ “ “	0′3″ x 0′7″		8[3]				8
“ “ “ “ “	0′8″ x 0′8″				4[4]		4
“ 18 “ “ “	3′6″ x 4′0″					1	2
“ “ “ “ “	4′0″ x 8′6″			1			1
“ 20 “ “ “	2′0″ x 6′0″						1
Steel Plate 1″ x ¼″	8′ 6″		1				1
“ “ 1″ x ¼″	4′ 2¼″		2				2
“ “ 1″ x ¼″	3′ 4″		1				1
“ “ 2″ x ⅜″	0′ 5″		10	10			20
“ “ 2″ x ⅛″	2′ 4″		2[5]				2
“ “ ⅛″ thick	0′11½″ x 0′11½″		2[5]				2
Angle Iron 5 x 5 x ⅜	0′ 1½″		2	2			4
“ “ 3 x 3 x ⅜	0′ 1½″	4					4
“ “ 1½ x 1½ x ¼	12′ 1⅝″	2					2
“ “ 1½ x 1½ x ¼	8′ 10¼″		1	1			2
“ “ 1½ x 1½ x ¼	8′ 6″		1				1
“ “ 1½ x 1½ x ¼	4′ 2¼″		2				2
“ “ 1½ x 1½ x ¼	9′ 0″		1	1			2
“ “ 1 x 1 x ¼	8′ 8″		1				1
“ “ 1 x 1 x ¼	4′ 6″		4				4
“ “ 1 x 1 x ¼	3′ 6″		2				2
“ “ 1 x 1 x ¼	5′ 6″			4			4
“ “ 1 x 1 x ¼	3′ 10″				2	2	18
“ “ 1 x 1 x ¼	6′ 0″					2	12
“ “ 1 x 1 x ¼	9′ 0″				2		6
T Iron 1½ x 1½ x ¼	9′ 0″	2					2
“ “ 1½ x 1½ x ¼	5′ 9¾″	4					4
“ “ 1½ x 1½ x ¼	12′ 1⅛″	1					1

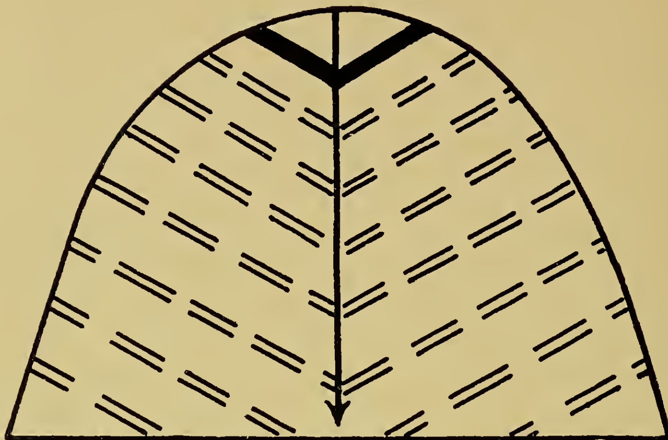
Bill of Materials

Four Cord Kiln

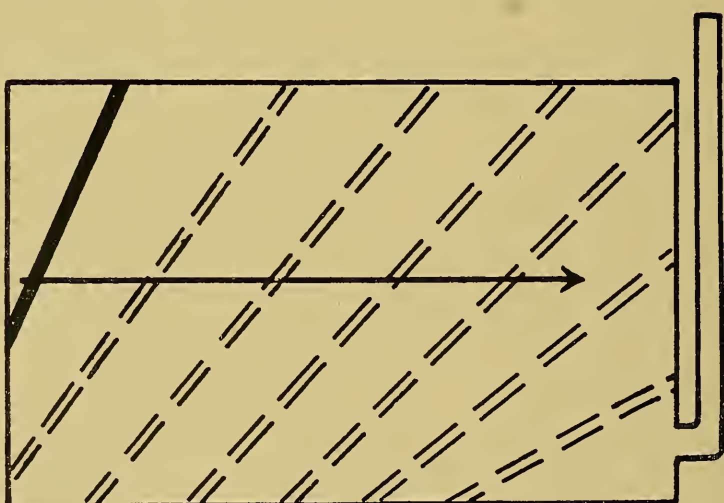
(Continued)

Kind of Material	Dimensions	Frame Fig. 8	Front End Panel Fig. 9	Rear End Panel Fig. 10	Top[1] Panel Fig. 11	Side[2] Panel Fig. 12	Total for Kiln
		Number of pieces					
" " 1½ x 1½ x ¼	6′ 0″		2	2			4
" " 1½ x 1½ x ¼	5′ 10½″		1	3			4
Rivets	¼″ x 1″		97	154	52	40	647
Machine Bolts	$\frac{5}{16}$″ x 1″	8		4	18		66
" "	$\frac{5}{16}$″ x 1½″	8	30				38
" "	$\frac{5}{16}$″ x 2½″			50		20	90
" "	$\frac{5}{16}$″ x 4″		28				28
" "	$\frac{5}{16}$″ x 4½″			12			12
" "	$\frac{5}{16}$″ x ¾″		20				20
" "	$\frac{5}{16}$″ x 7″		1				1
" "	⅜″ x 1½″	8					8
Stove Bolts, flat head	$\frac{5}{16}$″ x 1″	42					42
Steel Pins	$\frac{5}{16}$″ x 3″				8		24
Steel Pins	⅜″ x 4″	32					32
Steel Pipe 1″ diam.	1½″			50		20	90
" " " "	3″		28	12			40
Chimney Hole Cover	8″		2[6]				2
Galv. Smoke Pipe, 24 ga.	8″ x 24″		1[8]				1
" " " " "	10″ x 24″		3-4				3-4
" " " Elbow, 24 ga.	8″		2				2
" " " T 24 ga.	8 x 8 x 10		1				1
Wire Cloth, 1″ mesh, 10 ga. wire	5′0″ x 8′0″		1[6]				1
I—beam, 4″	12′ 4″						1[6]
Asbestos cement for insulation and sealing							

[1]Number of top panels, 3.
[2]Number of side panels, 6.
[3]For air inlet slides.
[4]For firing chimney covers.
[5]For making gas outlet collar.
[6]Not shown.
[7]All from 2 sheets 6′ x 10′.
[8]One-half length on either side of T.



A



B

FIGURE 1. Vertical section through a beehive kiln (A) and a rectangular kiln (B) showing several positions of the coaling zone. Arrow indicates direction of zone's movement.

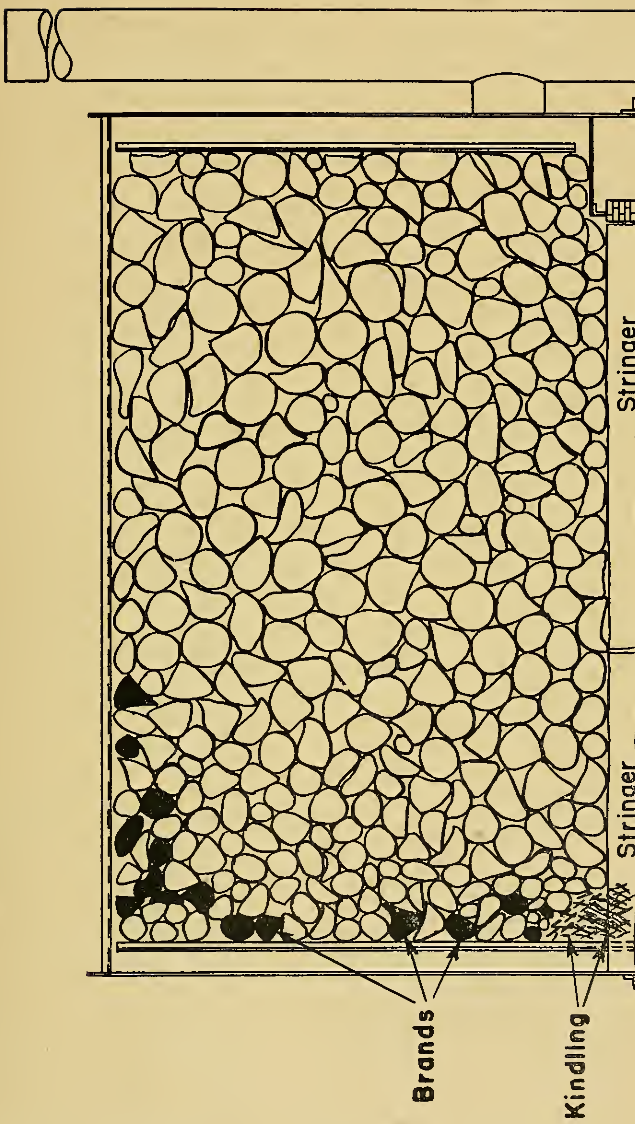


FIGURE 2. Vertical section through the one cord kiln showing the method of loading with wood.

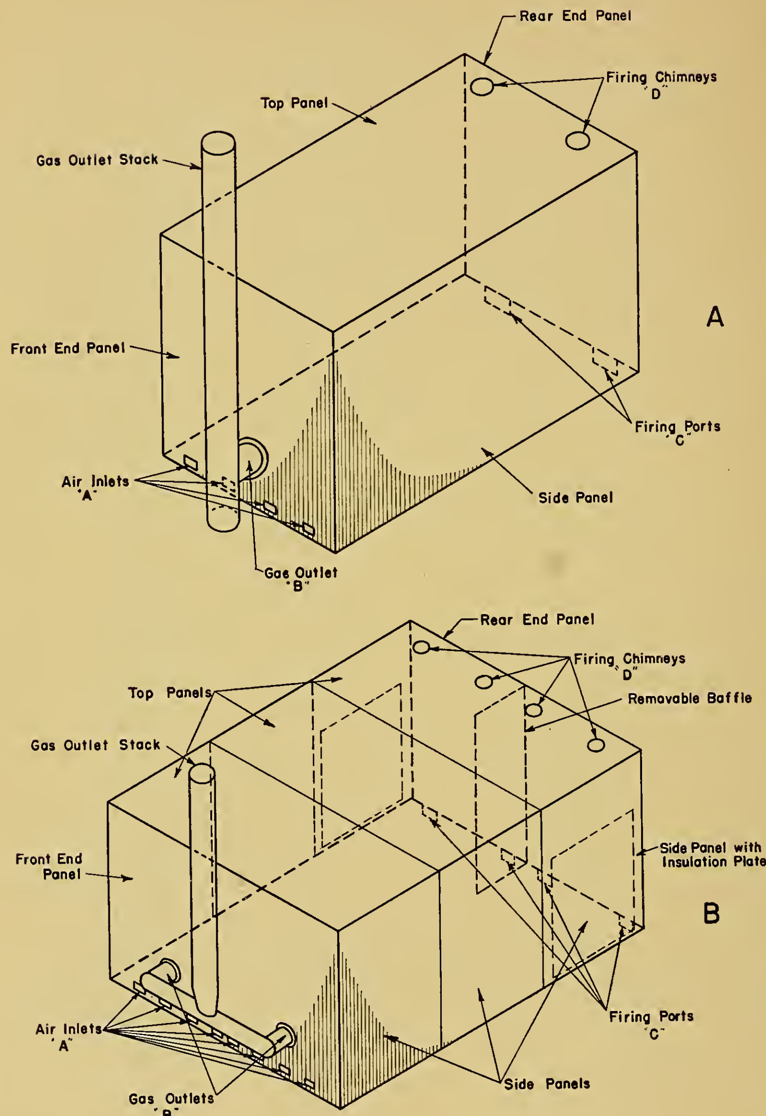


FIGURE 3. General View of the kilns showing relative position of the panels, firing ports, firing chimneys, gas outlets, air inlets, and gas outlet stack. A. One cord kiln. B. Four cord kiln.

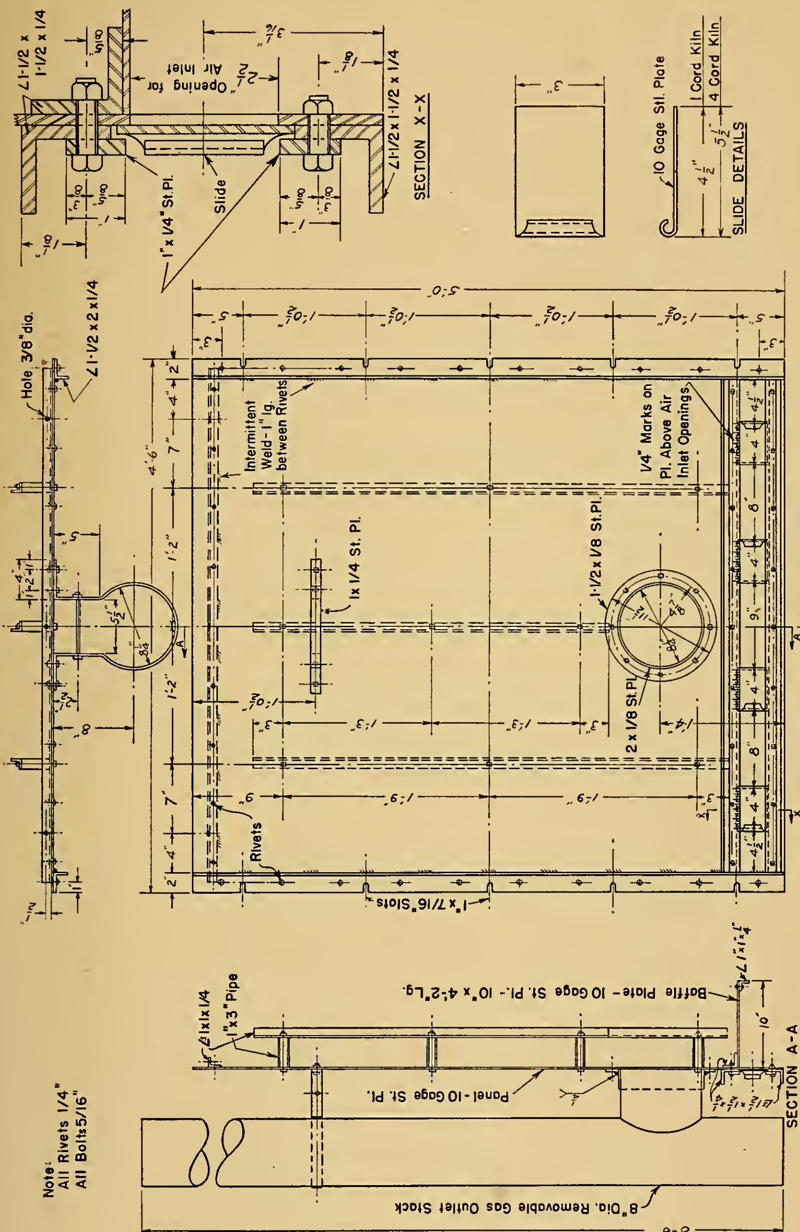


FIGURE 4. One cord kiln. Front end panel, gas outlet stack and details of air inlet slide construction.

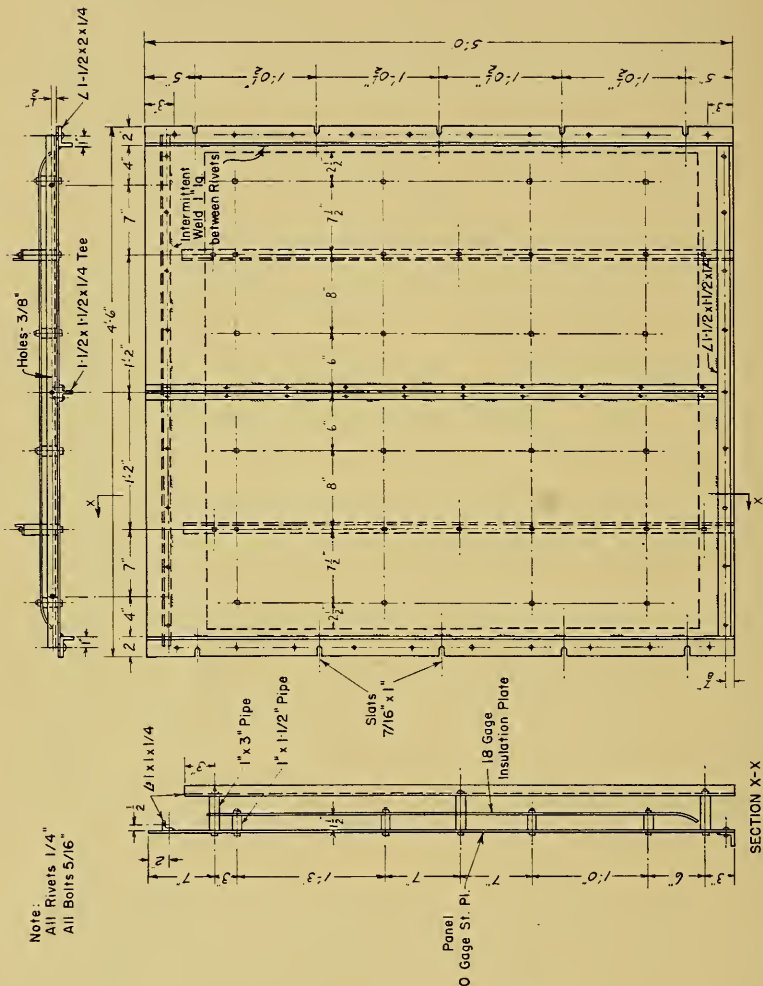


FIGURE 5. One cord kiln. Rear end panel.

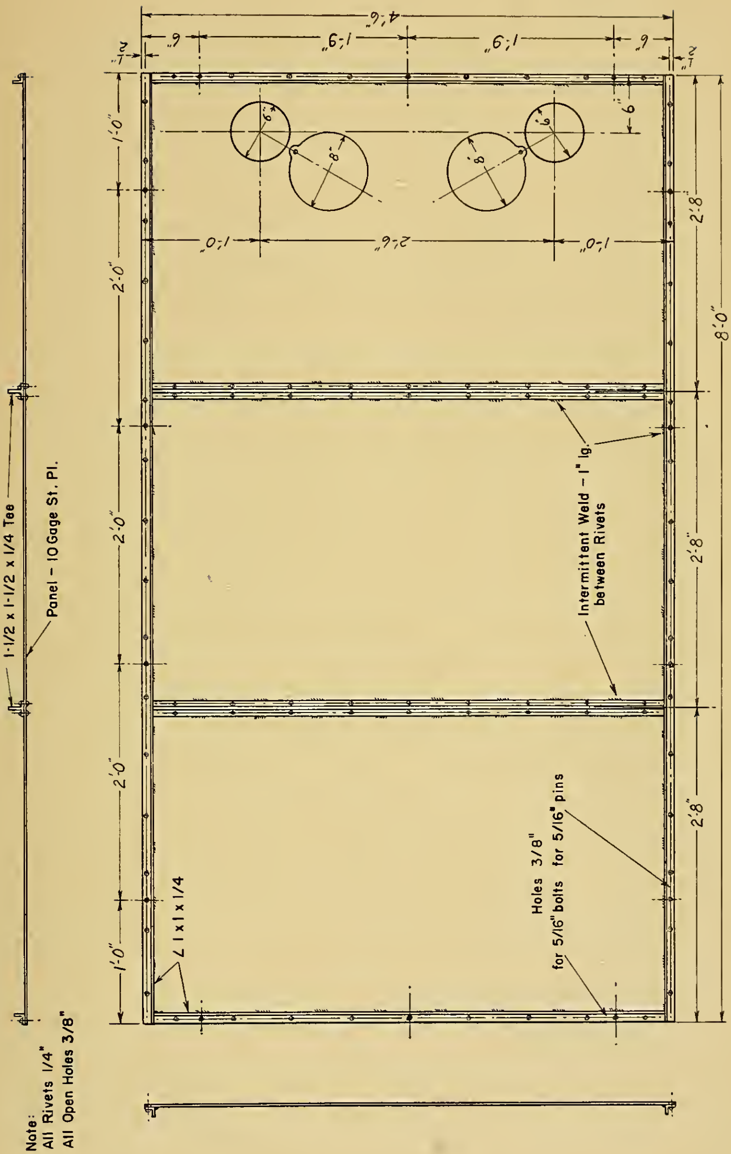


FIGURE 6. One cord kiln. Top panel.

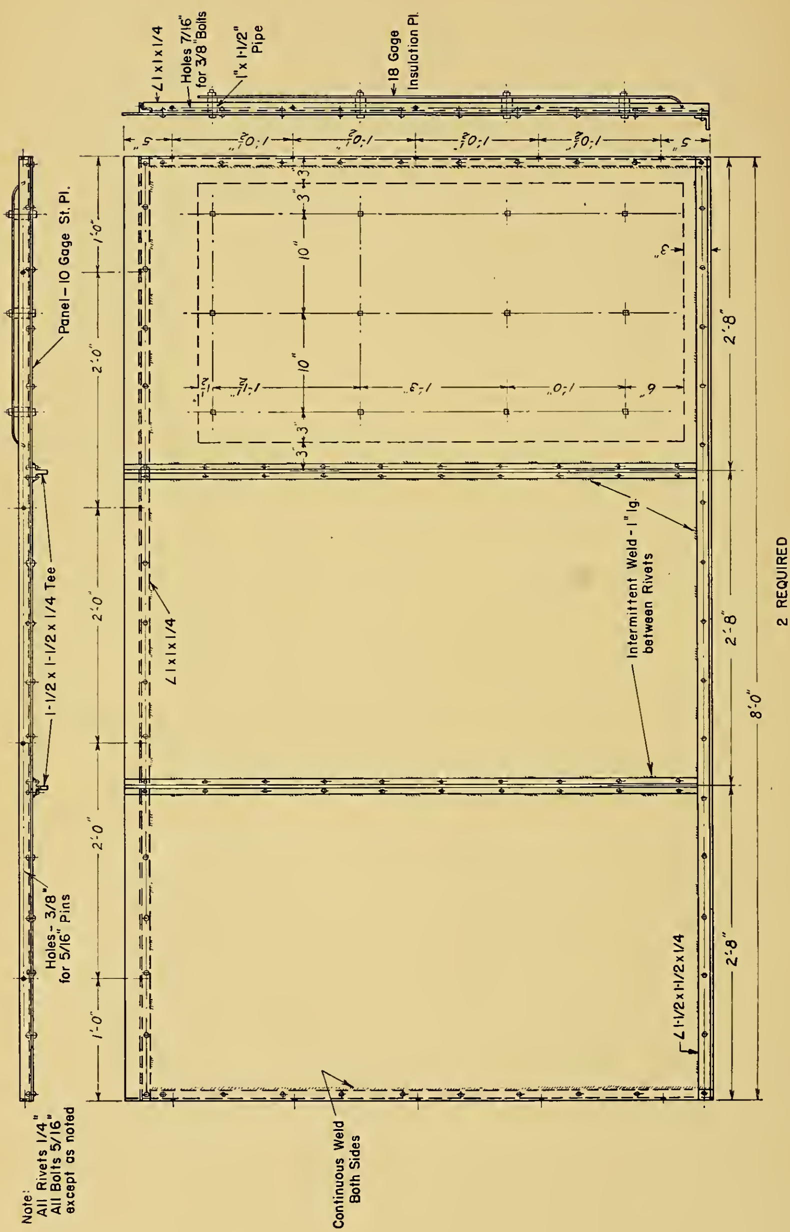


FIGURE 7. One cord kiln. Side panel.

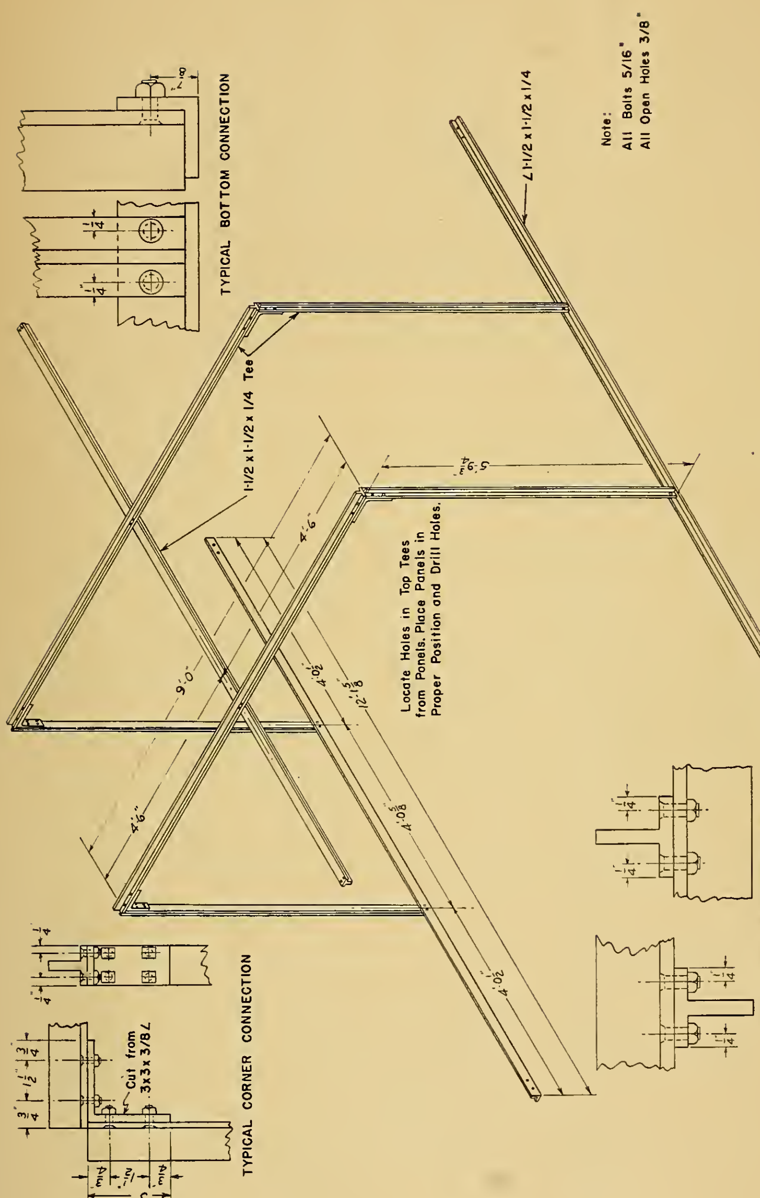


FIGURE 8. Four cord kiln. Structural frame.

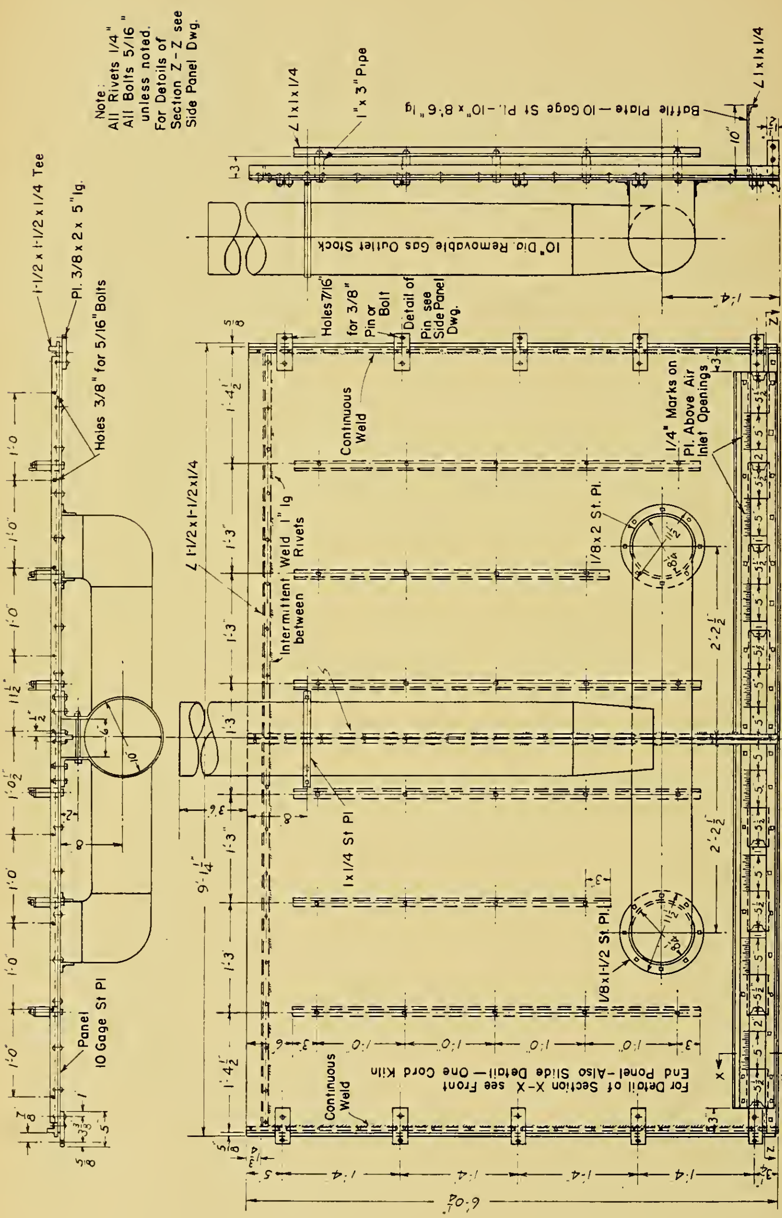


FIGURE 9. Four cord kiln. Front end panel and gas outlet stack. For details of air inlet slide construction, see Figure 4.

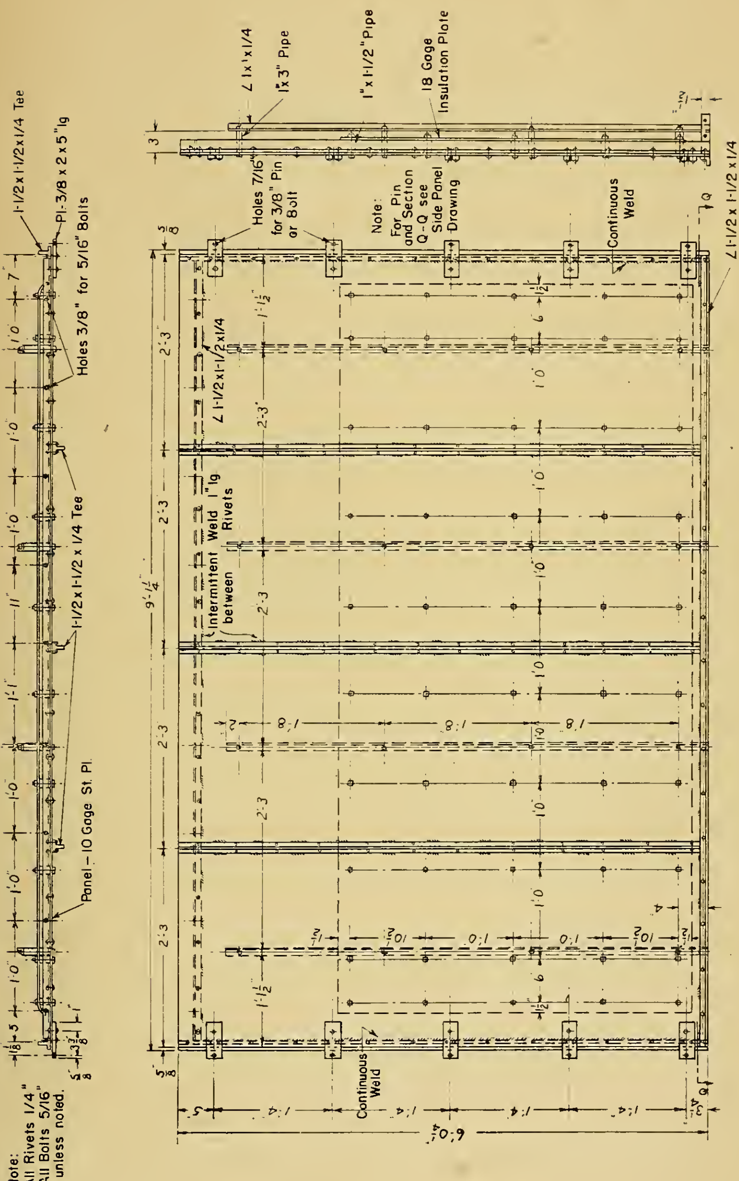


FIGURE 10. Four cord kiln. Rear end panel.

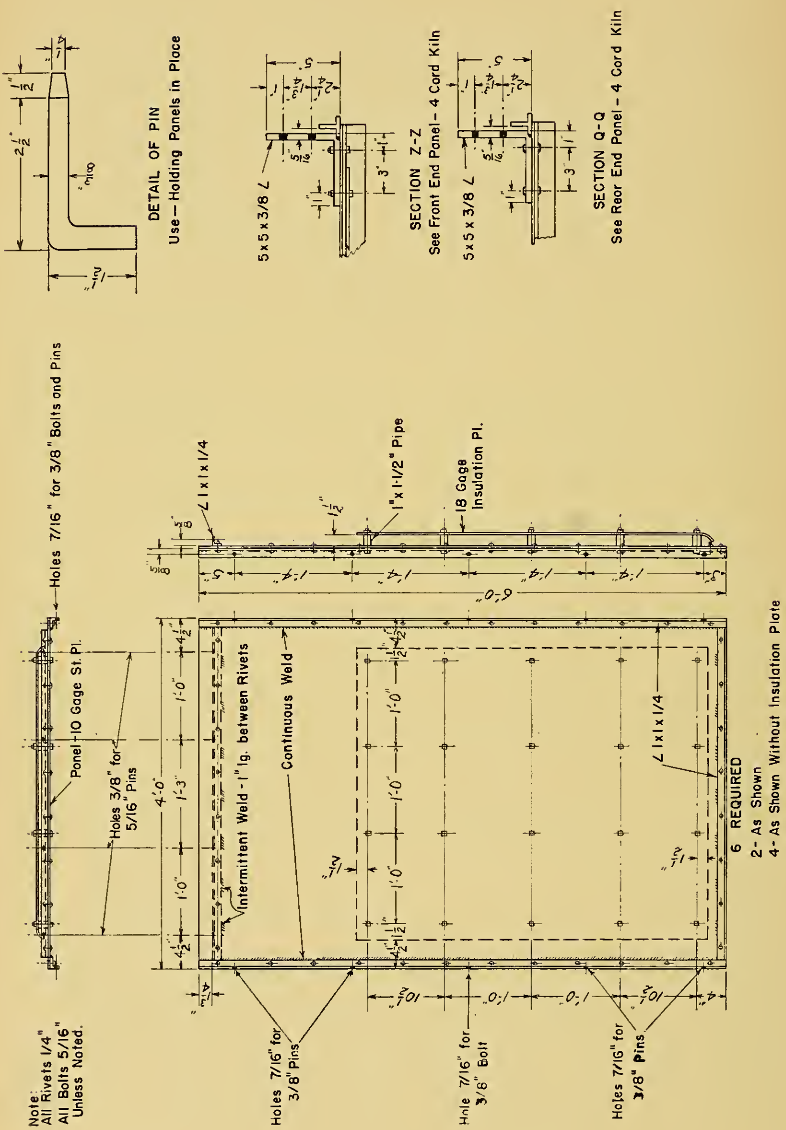


FIGURE 11. Four cord kiln. Side panel.

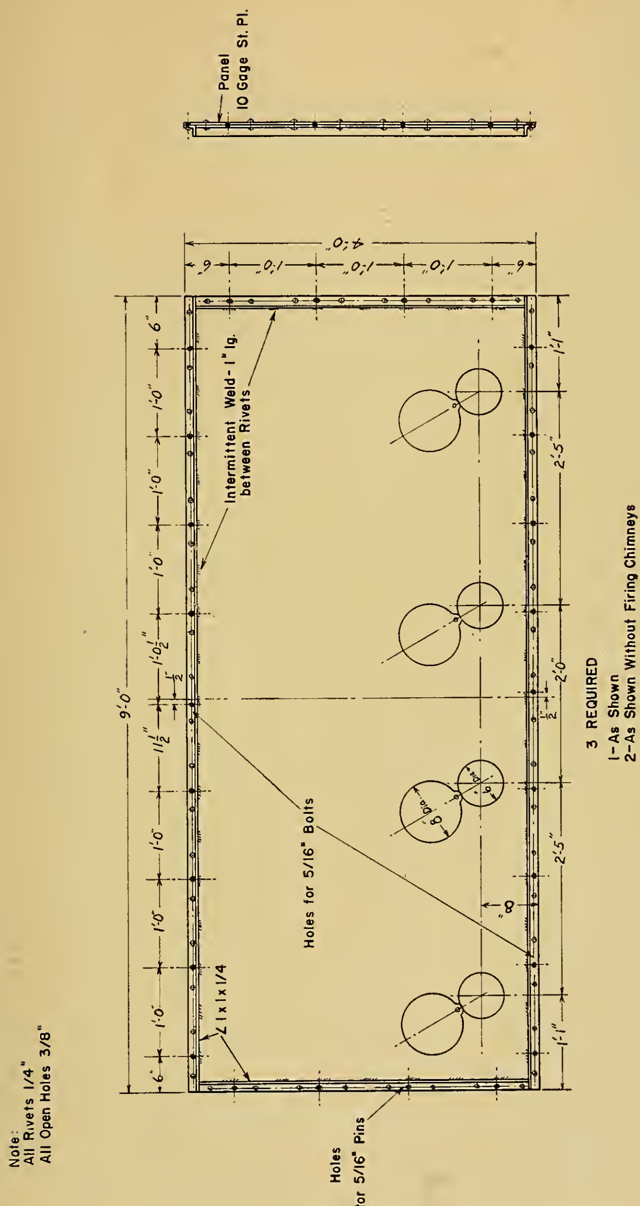


FIGURE 12. Four cord kiln. Top panel.